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PROJECT STATEMENT

Date: September 17, 1973

A. PROJECT SUMMARY

1. Statistical

Project Title: Soil Fertility in the Humid Tropics
AID/csd-2490

New or Extension: Extension - Three years

Contractor: Cornell University
Department of Agronomy
Ithaca, New York 14850

Principal Investigators: Dr. Matthew Drosdoff, Professor of Soil Science, Project Director
Dr. Richard H. Fox, Assistant Professor in Soil Science, Director of Operations in Puerto Rico
Dr. George C. Naderman, Research Associate, in Charge of Operations in Brasilia

Duration: June 30, 1969 to June 29, 1974
Current Authorization
June 30, 1974 to June 29, 1977
Proposed extension

Total Estimated Cost: $1,951,846

Previous years, to March 31, 1974 allocated to date	$1,126,846
April 1, 1974 to March 31, 1975	275,000
April 1, 1975 to March 31, 1976	275,000
April 1, 1976 to March 31, 1977	275,000
	1,951,846

Technical Specialist: Dr. John L. Malcolm
Alternate: Dr. Tejpal S. Gill

2. Narrative

Conclusive evidence is available to show that one billion five hundred million of the two billion acres of uncultivated land in the humid tropics consists of well-drained acid soils which can be made highly productive. This land is in the same areas where birth rates are high and the spectre of hunger is being seen more frequently. Even if the

developed countries produce a surplus again, the cost of foodgrains and of shipping is more than the LDCs can afford. These countries must produce most if not all the food for their own people. In addition, for many of the areas at least, farm crop export is the most likely way for them to earn essential foreign exchange.

The project, planned to span 10 years, became operational on June 30, 1969. Field experiments were initiated in Puerto Rico during May 1970. The University of Puerto Rico has been a major contributor under subcontract. Because of a mutuality of interest, the U.S. Department of Agriculture has continued active cooperation. Field work was begun in Brazil during July 1972 in cooperation with the Ministry of Agriculture and North Carolina State University. Exploratory discussions were held with officials of USAID/Accra, the University of Ghana, and the Soil Research Institute at Kumasi on the possibility of extending research to the acid soils of Ghana.

A progress report was made to the Research Advisory Committee at their 32nd Meeting, January 28-29, 1971. The current five year authorization expires June 29, 1974.

The work on this project, so far, has demonstrated beyond any doubt that the highly weathered, well drained acid soils of the tropics, represented by the experimental sites, have a very high production potential. However, this potential cannot be achieved by any single practice.

Nitrogen must be applied and managed in relation to crop growth and rainfall. Timing is critical. A highly promising rapid test for the nitrogen supplying power of soils is being tested.

The phosphorus status of these soils must be raised and maintained. Localized applications of phosphorus to minimize fixation are not adequate. Broadcast application proved much superior.

Toxic aluminum must be corrected or circumvented. It restricts root systems, limits plants' drought tolerance and their capacity to absorb nutrients. Deep incorporation of small amounts of lime is one control. Selection of acid tolerant crops or varieties another. The use of soluble calcium sources of nitrogen to speed penetration and subsoil "liming" is a third.

Liming to provide calcium and magnesium is essential on extensive areas of highly acid tropical soils. Much less lime is needed than temperate zone practice suggests.

Micronutrients, especially zinc. limited responses to fertilizer and lime. Farmers should try three pounds of zinc, as sulfate, per acre on Oxisols.

Water is a limiting factor in the humid tropics during most rainy seasons. One or two irrigations can make the difference between success and disaster.

Systematic pest and disease control is also essential.

Recent experiments using combined practices and a new corn variety have resulted in average yields of 140 bushels per acre and one plot with 180, double previously accepted "top" yields.

Halfway measures will not produce the desired results. Satisfying the needs for phosphorus and lime and developing water resources is a capital investment. Nitrogen, zinc and supplemental water are highly profitable annual inputs.

The skills and resources of cultivators must be sufficient for the complex combination of operations required for successful crop production. Uneducated farmers can learn these skills empirically and be assisted in obtaining the necessary resources.

The general purpose of the project during the period of the extension remains unchanged. It will seek to define the fertility factors which limit food crop production on the well drained acid soils in the humid tropics and to develop means of predicting when and where these limiting factors will be found. Then practical recommendations of field practice can be made without exhaustive field trials in every region of every country. Since it has been clearly established by this and other projects that there is no simple solution but rather that a complex package of practices must be designed, it follows that the research must be multi-faceted and must draw on the best science and judgment of people in many fields other than soil science.

Work will continue on nitrogen economy, phosphorus utilization, fixation and methods of application, aluminum toxicity and the interactions of phosphates and aluminum with lime. Now that plots have been maintained over a period of years to establish levels of performance and to allow cumulative effects of treatments, longer term crops, especially plantain and cassava, are being included among the test plants.

The field work was originally concentrated in Puerto Rico for efficiency and to allow ready access to scientists in disciplines other than soils. It was extended to Brazil and work in Ghana is proposed. Further cooperative work in Latin America, especially in the Dominican Republic and Colombia, is under consideration subject to the availability of staff and funds.

B. EXPANDED NARRATIVE STATEMENT

1. Background, Project History and Progress

a. Background

Despite the successes of the green revolution, world food production is short. It is essential to tap the available unutilized and

underutilized soil resources. The best estimates indicate that there are about 800 million hectares (two billion acres) still uncultivated in the humid tropics, more than is cultivated in the zone. Much of this land has a favorable topography and the soils are generally deep, well drained, and permeable. The main limiting factors are the very low soil fertility, soil moisture deficiency at critical growth periods and toxicity of aluminum and manganese which accentuate both. Conclusive evidence is available which shows that these soils can have high productivity at relatively modest cost provided that adequate soil, crop, and water management practices are used including the application of fertilizer nutrients in proper balance and amounts.

In addition to the extensive areas in the humid tropics which are not now under cultivation, most of the soils give poor yields under traditional management. The introduction of modern technology can increase productivity several fold.

b. Project History

The contract for the first five years of the project became effective on June 30, 1969. The major objective was to determine economic amounts and methods of application of nitrogen, phosphorus, potassium, liming materials, and micronutrients to help realize the productivity potential for food crops on the acid soils of the humid tropics. After two years added emphasis was given to soil moisture studies in relation to soil fertility. It had been assumed that in the humid tropics, especially during the rainy season, soil moisture was not much of a limiting factor. However, it was found that short dry periods of a week or two during the rainy season could seriously affect crop response to fertilizers and lime. This was especially true when the plant roots were restricted to the surface soil and not able to exploit subsoil moisture because of the presence in the subsoil of toxic concentrations of aluminum and/or manganese or a lack of calcium or other essential macro or micronutrients.

The project was designed so that the results would be applicable to extensive areas in Latin America, Africa, and Asia. The field research was initiated in Puerto Rico in cooperation with the Agricultural Experiment Station of the University of Puerto Rico. A Cornell staff member was stationed in Puerto Rico and has served as project leader in the field. Research personnel of the United States Department of Agriculture stationed in Puerto Rico also have collaborated. Consultation of well-qualified Puerto Rican scientists in crop science, plant pathology, entomology, statistics, and other complementary disciplines was an invaluable asset.

In July 1972 field experiments supplemented by greenhouse and laboratory studies were initiated at the Agricultural Experiment Station near Brasilia in cooperation with the Brazilian Ministry of Agriculture and in collaboration with the University of North Carolina. The soils in the experiments

are representative of vast areas of the Campo Cerrado. Though these acid soils are similar in many characteristics to those under investigation in Puerto Rico, there are important differences and the climatic environment is different.

A Cornell staff member is stationed in Brasilia and serves as leader of the field operations which are planned jointly by the soil scientists of the Ministry of Agriculture, North Carolina State University, and Cornell University. Research assistants from the three cooperating institutions are participating in the project.

Preliminary discussions have been held with the Soils Research Institute at Kumasi, Ghana regarding collaboration in soil fertility studies. There is a substantial area of acid soils in Ghana similar in many characteristics to those under study in Puerto Rico. It is planned to develop a collaborative arrangement in Ghana similar to that in Brazil.

c. Progress to Date

The overall objective of the research is to increase food production in the humid tropics through efficient soil and water management practices. The experimental work in Puerto Rico and Brazil has focused on the following:

(1) Nitrogen requirements and efficiency of nitrogen utilization by important food crops;

(2) Phosphorus requirements, the reactions of phosphate fertilizer in acid tropical soils and the residual effects of phosphates;

(3) Soil acidity and liming with particular attention to the control of aluminum toxicity;

(4) Soil moisture studies related to soil fertility requirements;

(5) Micronutrient needs;

(6) Clay mineralogy.

Experiments have been conducted at five locations in Puerto Rico and one in Brazil. The soil at each site is representative of extensive areas of acid soils in the humid tropics (Oxisols and Ultisols). The results of the experiments are described below:

1) Puerto Rico

a) Nitrogen Experiments

(1) Corn and sorghum field experiments: These experiments were begun in April and May, 1970, and the last crop was harvested in the winter of 1972. They were designed to test the efficiency of utilization of nitrogen applied as urea at different rates, times of application, and the residual effects. A total of 15 corn and 3 sorghum crops at five sites on representative Oxisols and Ultisols were harvested. The yield data of grain and stover were supplemented by several thousand soil and plant analyses to help in the interpretation of the results. The main conclusions are:

(a) The post-plant application of nitrogen (30-35 days after planting) was generally much more efficient in increasing yield than pre-plant applications.

(b) When the yield potential of the hybrid corn was not limited by drought or disease, the recovery of post-plant applied nitrogen by the crop was substantially higher than recovery of the pre-plant, 50 to 60 percent as compared with 30 to 40 percent. The amount recovered in the post-plant treatments is about the same as that observed in temperate regions and indicates that unusual losses do not necessarily occur under these particular soil and climatic conditions.

In one extreme case there was no recovery of pre-plant fertilizer nitrogen by sorghum. Heavy rains came shortly after the nitrogen was applied. Also, the sorghum was very shallow rooted due to its sensitivity to the aluminum in the subsoil.

In summary, post-plant nitrogen applications generally resulted in higher yields, higher nitrogen and protein content of the crop, and less nitrogen as a potential pollutant of water supplies lost from the soil.

(c) Generally, near maximum yields of corn were obtained with only 60 lb/acre of applied nitrogen. Apparently there is enough nitrogen in the organic matter in these soils and in the crop residues to supplement substantially the applied nitrogen. In one location on a clayey Oxisol, the nitrogen fertility was built up to such an extent that yields of 100 bushels per acre of corn grain were obtained without added nitrogen. Plant uptake of about 125 lb/acre of nitrogen has been recorded on plots receiving no additional nitrogen.

(d) Sulfur coated urea was found to be no more effective than regular urea in the yield response of sorghum and corn and the recovery of the nitrogen by the crop was less.

(e) The last crop of corn was planted in April and May 1972 at three sites to determine the residual effect of previously applied fertilizer nitrogen on yield. At one location there was no indication of any residual effect. The yields were only about 50 bushels per acre in comparison with treated plots which averaged more than 100 bushels per acre. At another site some residual effect was noted from a high nitrogen application to the preceding crop but in this case all yields were substantially reduced because of a severe drought. At the third site no residual effects were observed because the nitrogen supplying power of the soil was so high that no yield increases were obtained in the plots with added nitrogen. The average yields of both treated and untreated plots were about 100 bushels per acre.

(f) A maximum yield of about 100 bushels of corn was obtained with the best corn variety available--one developed in Jamaica for the humid tropics. Because of the cost of control of insects, diseases, and nematodes in the experimental plots, it is apparent that high yielding varities more resistant to these pests will need to be developed for high productivity of corn in the low humid tropics. The results of the field experiments demonstrate that the economic management of the nitrogen fertility is much less of a problem than pest control. The other major limiting factor which merits greater attention is the provision of adequate soil moisture either through supplementary irrigation or by techniques to provide greater root penetration to exploit subsoil moisture.

(g) The results of the field experiments supplemented by soil and plant analyses indicated that the soils may supply a substantial amount of nitrogen from the mineralization of organic matter. Representative samples of a number of Oxisols and Ultisols covering a wide range in content of organic matter were continuously cropped in a greenhouse study to measure the amount of nitrogen removed and determine how this correlated with the amount extracted by chemical procedures. The results demonstrated that a laboratory chemical method can provide a means for evaluating the capacity of the soils to supply nitrogen. This was tested in the field with three soils and it was found that there was excellent correlation between plant uptake and a simple laboratory

analysis for extractable nitrogen. If this test should prove to be generally effective, it would be possible to make much better recommendations for nitrogen fertilization for a target yield.

(2) Cassava Field experiments: As cassava is one of the most important food crops in the tropics, experiments have been initiated this year at three of the experimental sites to determine the yield response to levels and methods of application of nitrogen. A high protein variety, Llanera, is the test crop.

(3) Plantain field experiments: Field experiments have been started with plantain during the past year to measure responses to nitrogen and other fertilizer nutrients on representative acid Ultisols. The first experiment has just been harvested and responses to the different treatments have not yet been analyzed. However, the yields on all plots are very high and an average of 12 tons per acre of the edible portion of the fruit is estimated. In the past, nematode infestation has severely limited plantain yields especially the ratoon crops. The availability of a new nematocide, Dasanit, has made it possible to reach very high levels of production under good management especially if the ratoon crops will continue to be highly productive as anticipated.

b) Phosphorus Experiments

Field experiments with corn and sorghum were designed to define the response curves for applied phosphorus fertilizers on representative Oxisols and Ultisols, to measure the relative efficiency of banded versus broadcast fertilizer phosphorus, and to estimate the residual effects of the broadcast and banded fertilizer phosphorus.

In one location on a clayey Ultisol no response to any of the phosphorus treatments was obtained with sorghum or corn which followed. Chemical soil tests and a greenhouse assay had indicated that this soil should respond to applied phosphorus fertilizers. The site had been under cultivation for many years and apparently enough residual phosphorus was available to meet the needs of both crops.

Another site on a representative Ultisol was selected for the phosphorus field experiment. Again soil and greenhouse tests indicated severe phosphorus deficiency. During the cooler winter season, the application of 160 lbs/acre of phosphorus doubled corn yeilds over the check plots. In the summer the response of corn to applied phosphorus fertilizer was still very striking during the first two months. By harvest time, however, the differences had diminished considerably, although there was some yield increase with phosphorus treatments. It was postulated that the lack of response during the summer period in contrast to the response during the

winter season was due to the greater mineralization of organic matter and release of organic phosphorus with the higher summer temperatures. This has prompted an investigation of the importance of organic phosphorus in the acid soils of the humid tropics and the development of a soil test which would measure the release of organic phosphorus during the growing season as well as the availability of inorganic phosphorus and thus provide a better estimate of phosphorus requirements under different soil conditions.

In order to get information on a wider range of phosphorus deficient soils on responses to applied phosphorus fertilizer and the interaction with lime treatments, surface and subsoil of three representative Ultisols and Oxisols were placed in 55 gallon bottomless steel drums sunk in the ground. During the early stages of growth of the first crop, sorghum, there were pronounced differences in plant response to applied phosphorus but at harvest time the differences were much less. However, the high phosphorus treatments did produce significantly higher grain yields. Subsequent cropping with corn twice and then rice have shown responses to applied phosphorus similar to that of the first crop of sorghum.

It was anticipated that the sunken drum experiments with phosphorus would more nearly approximate field conditions than the greenhouse tests which correlate poorly with the field experiments. However, the phosphorus experiments in the sunken drum also did not correlate well with the field trials. This highlights the importance of field trials to verify any conclusions on phosphorus responses which are drawn from greenhouse, sunken drum, or chemical soil tests.

c) Liming and Soil Acidity

Field experiments with a number of crops using different levels of lime have been conducted at five locations on representative Oxisols and Ultisols. These have been supplemented with greenhouse studies. The crops grown were corn, sorghum, green beans, sweet potatoes, rice, and soybeans. The objective of these experiments was to determine the minimum levels of lime required for optimum yields of the various crops under the different soil conditions and to devise improved laboratory methods for predicting the minimum lime requirements.

No response to liming was found above pH 5.1 with any of the crops tested. In some cases there was little or no response above pH 4.5. Sweet potatoes, for example, appear to be quite tolerant to very acid soils with relatively high amounts of soluble aluminum. There was no significant increase in yields as the pH was increased from pH 4.1 to over 5.0. Similarly, rice appeared to be relatively tolerant to acid soils.

Yields of corn on a clayey Ultisol were doubled when the pH of the soil was increased from about 4.5 to 5.1 with two tons of lime per acre. However, on a clayey Oxisol with about the same initial pH, addition of lime did not increase corn yields significantly. The Ultisol contained a relatively high concentration of soluble aluminum which is toxic to many crops while the Oxisol had little or no soluble aluminum, although the soil had a relatively low pH.

Although the yield of green beans was increased by the application of lime, apparently this crop is not as sensitive to aluminum toxicity as corn. On a highly acid Ultisol the yield of green beans increased from about five tons per acre to over 6.5 tons per acre with just enough lime applied to increase the pH to about 5.2. This soil has a relatively high content of organic matter and it is postulated that organic matter also has some effect on neutralizing aluminum toxicity.

Some crops such as sorghum are very sensitive to soluble aluminum and their rooting depth on Ultisols is limited to the depth to which lime is applied. During short dry periods the roots do not reach the subsoil moisture because of the presence of toxic concentrations of aluminum; consequently, the plants suffer from drought. A field experiment with sorghum was begun this year to determine the effectiveness of subsoil liming for increasing root penetration to exploit subsoil moisture thereby minimizing the serious moisture deficits during the dry periods. Subsoil liming will be compared with surface applications of lime and other calcium compounds. Recent studies have indicated that surface applications of calcium nitrate may be effective in neutralizing subsoil aluminum toxicity.

In order to get more information on the rooting behavior of corn, sorghum, and stargrass relative to the concentration of soluble aluminum in a representative Ultisol and Oxisol, a greenhouse test was conducted supplemented by chemical studies. Sorghum roots were highly sensitive to soil solution aluminum, corn roots moderately sensitive, and stargrass roots tolerant. Soil solution aluminum concentration can be calculated satisfactorily from soil pH and electrical conductivity of the saturated paste extract.

In summary, the liming experiments have demonstrated the wide range of tolerance of various crops to soil acidity and aluminum toxicity. In general much less lime needs to be applied on the acid soils of the humid tropics for optimum productivity than has been previously thought. A more accurate method for predicting the lime requirement is being developed for the soils of the humid tropics. The importance of counteracting subsoil acidity to increase root penetration and reduce moisture stress during dry periods has been demonstrated and practical methods for field application are being tested.

d) Soil Moisture Studies

During the course of the soil fertility field experiments, it became apparent that water stress on the growing crop during the dry periods in the rainy season was a serious factor limiting the response to fertilizer nutrients. Consequently, preliminary soil-water experiments were conducted in Puerto Rico on the different soils at the sites of the four locations of the field experiments. A typical experimental design consisted of a 3 meter by 3 meter plot instrumented with tensiometers to a depth of 120 cm. The plot was flooded with water and covered with plastic to stop evaporation. Water movement was monitored during infiltration and drainage for up to 35 days using the tensiometers.

In the tension range, 0 to 3/4 bar, correlation of soil-water content with soil-water tension was determined with undisturbed soil cores in the laboratory on Tempe Cells and on a pressure plate apparatus. At higher tensions disturbed samples were run on pressure plates. Use of these data permits conversion of soil-water tensions to values of soil-water content. Gravimetric samples for soil-water contents were taken in the field as a check against soil-water contents as determined indirectly using tensiometers.

The results are summarized as follows: (1) water infiltration into all soils was very rapid, the rate typically reaching about 8 cm/hr after one hour of continuous flooding; rate and amount of infiltration were inversely related to initial soil-water content; (2) on the clayey Ultisols lateral water movement downslope was a significant factor in observed high rates of infiltration; (3) generally, values of soil-water tension after two to three days of free drainage do not exceed 20-80 cm of water (roughly 1/50 to 1/12 bar); field capacity was found to be about 1/15 bar for a sandy Oxisol and 1/20 bar for the clayey Oxisols and Ultisols; (4) in the two Oxisols studied, the bulk of the water is released between field capacity and 1 bar; in contrast to a high proportion of the water in the two Ultisols was available at tensions above 1 bar; (5) both the sandy Oxisol and clayey Oxisol tended to dewater at low tensions whereas soil-water releases in the Ultisols extended over a wider range of tension; the sandy Oxisol failed to release appreciable water above 1 bar of tension; (6) calculations of capillary conductivity indicated that it was highly water content dependent; it was estimated that only 10 percent of the water required for evapotranspiration might be supplied as upward water movement from the soil beyond the root zone; (7) undisturbed core samples are required to measure water retention in the wet range (0-3/4 bar) and disturbed samples in the dry range (1-15 bars); an overestimation of soil-water storage will be made by employing either disturbed sample techniques at low tensions or undisturbed core samples at high tensions.

e) Micronutrient Studies

In a recent zinc experiment with corn at one of the nitrogen experiment sites, a new hybrid produced up to 180 bushels of grain per acre with the average for all plots between 130 and 140 bu/acre. This sets

a new standard for these soils and for Puerto Rico. Previously the yield ceiling for the project had been about 100 bu/acre which was a record for the Island. Zinc supply was not critical for corn at this site.

f) Clay Mineralogy Studies

The objective of these studies is to characterize the clay minerals in the soils of the field experiments in order to relate them to the responses to applied nutrients. To date, the characterization has been completed on five soils: one sandy Oxisol, two clayey Oxisols, and two clayey Ultisols. Weatherable minerals which would furnish a reserve of bases could not be detected in the soil fraction larger than 50 microns. The sand fraction of all the soils was dominated by quartz except that in the lower depths of the clayey Ultisol (Los Guineos) where gibbsite was also present. The clay fractions of each of the five soils were homogenous in mineralogical composition throughout the depth of the profile. Kaolinite, amorphous material and chlorite dominated the clay fractions from all of the soils.

Continuing studies focus on the interaction of the noncrystalline iron and aluminum oxides and organic matter and its influence on the charge characteristics of the surface horizons. The soil mineralogical properties which influence the absorption and release of added phosphorus is being determined. The affinity of the exchange complexes for potassium relative to that of calcium, magnesium, and aluminum is being measured on those soils which have a relatively low level of potassium.

2) Brazil

The soil fertility research initiated in July, 1972 at the Agricultural Experiment Station near Brasilia is essentially an on-site extension of the work in Puerto Rico. The research is being conducted jointly with the Brazilian Ministry of Agriculture and North Carolina State University. The site at the experiment station is representative of extensive areas in the Central Plateau of Brazil (Campo Cerrado) which covers about 450 million acres, almost 20 percent of the land area of the country. Most of this area is used for extensive grazing. The soils are predominantly Oxisols and though similar in many respects to the Oxisols of Puerto Rico, there are important differences and the climate is different with a long dry season. Yet the soils have high potential productivity with proper soil and water management.

The experiments in Brasilia are similar in design to those in Puerto Rico. Responses to different levels and methods of application of nitrogen, phosphorus, lime, micronutrients and other elements will be determined. From the work in Puerto Rico and preliminary studies in Brazil, a major

focus is on soil moisture problems related to soil fertility. Irrigation facilities are available so that continuous cropping is possible throughout the year. Though the rainfall is high during the six or seven months of the rainy season, analysis of long term weather records show that there are periods of drought of five days or more during a critical growth period which can seriously reduce yields in four out of five years. The relative high percentage of soluble aluminum and the very low calcium and magnesium content factors in these soils limit the productivity of many crops.

The initial field experiments were begun in November and December, 1972 to measure responses of corn during the rainy season to different levels and methods of application of nitrogen, phosphorus, lime, and zinc. Following the harvest in March and April, 1973, a dry season crop of corn under irrigation was planted in June. To complement the soil fertility studies, soil moisture research was initiated to: (1) determine the corn yields under various levels of water applied and/or used by the crop; (2) study the interaction between depth of incorporation of lime and utilization of soil moisture; (3) assess the probable reduction of yield caused by the dry periods, "veranicos," during the rainy season; (4) determine the difference, if any, in yields of corn between wet and dry seasons; (5) determine water utilization by corn as it relates to daily climatic parameters.

The results of the experiments are summarized below:

a) Nitrogen Tests

Yields of the first crop of corn increased from about 50 bushels per acre at the lowest level of applied nitrogen (20 to 40 pounds per acre) to over 100 bushels per acre at the highest levels (120 to 140 pounds per acre) of applied nitrogen. The basic treatment for all plots included the application of 360 pounds per acre of P_2O_5 (180 pounds applied broadcast as simple superphosphate, plowed under and rototilled and 180 pounds as treble superphosphate banded at planting). The results of the phosphorus experiment summarized next indicates that a basic treatment of higher levels of applied phosphorus would probably have given higher yields at the same levels of nitrogen.

b) Phosphorus Studies

The most surprising results of the first rainy season crop was the greater effectiveness of simple superphosphate applied broadcast in comparison with that banded. For example, 300 pounds per acre of P_2O_5 applied broadcast resulted in yields of about 100 bushels per acre, but the same amount banded gave yields of about 75 bushels per acre. With increased amounts of P_2O_5 applied from 35 up to 1,150 pounds per acre, yields increased from about 36 to 130 bushels per acre.

c) Lime Experiment

This experiment compared different levels of lime, each level incorporated at two depths, 0 to 6 inches and 0 to 12 inches. In addition to determining the effect of levels of lime applied, an important objective was to determine if the deeper incorporation of lime increased the rooting depth sufficiently to permit exploitation of subsoil moisture during the short dry period which occurs during the rainy season. It was observed that wilting occurred on the shallow lime treatments generally about three days before it occurred on the deeper lime treatments. This was reflected in the yields which were about 20 percent less where lime was incorporated in only 0-6 inches. It appears that one or two tons of lime per acre is sufficient for maximum yields.

d) Soil Moisture Studies

Preliminary data from the present dry season irrigated corn crop indicate a good correlation between depth of lime incorporation and soil water utilization. The water utilization is measured with tensiometers installed at 6, 12, 24 and 36 inch depths and gypsum blocks at 6 and 12 inches depths. Six different levels of irrigation are being used and the water applied to each plot is measured with an in-line flow meter.

Visual observations on water stressed plants indicate a linkage between phosphorus deficiency and water stress.

Field observations supported by soil water data indicate that corn plants watered only every two weeks and thus subject to four to eight days of temporary wilting use less water after it is supplied than plants which are irrigated weekly. A possible explanation is a temporary root inactivation or metabolic changes within the plant which result in a "hardening" of the leaves. In contrast to the reduced water utilization by water stressed plants, the plants receiving the most frequent irrigation use water out of proportion to their apparent vegetative growth.

e) Zinc

Without application of some zinc, corn will not grow on this soil. Zinc levels of 1, 3, 9, and 27 pounds per acre were compared and little or no increased yield was obtained above 3 pounds per acre. Yields of 130 to 140 bushels per acre were obtained from the plots with alequate zinc.

3) Extension of results of field research

Although available information and maps indicated that the soils at the experimental site are extensive in the Central Plateau of Brazil, it was not certain to what degree some of the differences in the associated soils would affect management needs.

A team of two U.S. and four Brazilian soil scientists concluded after an intensive field survey that the results at the Experiment Station at Brasilia should apply in principal to extensive areas of the Campo Cerrado, although local variation is to be expected. They recommended that at least one more site, on a different soil, be established to broaden the applicability of the research.

Short periods of dry weather during the rainy season seriously reduce yields in the Campo Cerrado and supplementary irrigation prove profitable for many crops. Climatic data indicate that small ponds could provide a reliable and economical source of water for this purpose.

2. Significance to A.I.D. Objectives

This project is aimed at providing more food and a better balanced diet for the people of developing countries. The research is directed toward better use of land resources in the humid tropics. It will provide the soil and crop response data on which reasonable sector analyses can be based, setting the range of opportunity in the future.

The practices developed should be particularly useful to the farmer of limited means and should not involve long-term capital outlays. If the return on investment is high, these practices can help give the subsistence farmer a better living and perhaps a surplus for savings and a few luxuries.

Productive employment of people in the developing countries is a major objective of A.I.D. Successful research under this project will increase job opportunity both on the farm and in the community as a whole. It will allow more intensive farming. It will encourage the development of new farming areas creating new jobs. Through greater output it will create a substantial number of jobs in the community in purchasing, storage and transport of food and other farm products.

3. Relation to Existing Knowledge

The National Academy of Sciences under contract AID/csd-2505 established a Committee on Tropical Soils to assess the present knowledge of the soils of the humid tropics and to establish the major research needs. At the same time, North Carolina State University, under its A.I.D. contract csd-2806, published "A Review of Soils Research in Tropical Latin America."

The reviews indicate that research on soil nitrogen and nitrogen transformation in soils of the tropics is very spotty. Tropical agriculture appears to have depended heavily on research in temperate areas for fundamental information on soil nitrogen. However, there are some soil nitrogen and organic matter transformation processes in the tropics which are quite different from those commonly observed in temperate regions. These differences result largely from differences in climate.

For recently cleared and cultivated lands, there is little information on the rate of decline in soil organic nitrogen and the period at which equilibrium will be established. Informati , relative to nitrogen movement in the soil is scarce. Knowledge of shifting cultivation in the tropical world is very limited and only part of the puzzle has been looked at yet. A systematic approach, measuring changes in soil properties as a function of time is needed.

Very little work has been done on the amount of fertilizer phosphorus required to bring the soil up to optimum levels. There is also a need to study the residual effect of phosphorus from a given application of phosphorus. A reliable and inexpensive test to diagnose phosphorus deficiency in tropical soil is urgently needed. This will require calibration with field trials under different soil and climatic conditions.

Soil acidity and liming are still very poorly understood in the management of tropical soils. Information is required on the amount of exchangeable aluminum in relation to total exchangeable bases and on the interactions between aluminum and the other cations. The effects of liming, which are known to vary radically from one soil to another, must be understood before rational prediction of the effects on the plant is possible.

These reports point out the necessity to optimize soil moisture utilization, maintenance of good soil structure for encouraging plant growth, and show the lack of evidence on how to reach these objectives.

Micronutrient deficiencies are likely in many areas of the humid tropics with the intensification of cultivation that involves substantial use of fertilizers, lime, and improved cultural practices. Investigation of these interrelationships is needed as well as identification of soil properties related to micronutrient deficiencies.

In these reviews much emphasis is given to the need for long-term experiments for developing soil management systems including multiple cropping and rotations that are an improvement over those currently used in traditional agriculture in the tropics. Such experiments require repetition at several sites on carefully characterized soils and climates that are representative of extensive areas. The priorities assigned to specific research problems will be locale dependent; for example, in some areas soil moisture or soil structure will be most important, in others, the nitrogen supply, phosphorus requirements, or soil acidity. Most probably a combination of two or more problems will be involved.

4. Relation to Other Research

This project is essentially a component of an interlocking research program on soils and water management in the tropics. There are two consortia, the one on soils, consisting of Cornell University, the University

of Hawaii, North Carolina State University, Prairie View A & M College, and the University of Puerto Rico. The other on water consists of Utah State University, Colorado State University and the University of Arizona, all funded by AID 211(d) grants. Each university is building its capability in a separate area of the soil and water management system for use in the tropics.

North Carolina State University, in addition, has two contracts with AID that relate to soil fertility. One is a centrally funded research contract that is studying agro-economic management systems for the tropical soils; the other, a Latin America regional technical assistance program geared to soil fertility evaluation programs, soil testing, the establishment of soil testing laboratories, and training of personnel.

Utah State University and Colorado State University each have separate research contracts with AID. These universities are investigating on-farm water management problems in Latin America and in Asia, respectively. Their studies include work on crops, fertilizer, drainage, salinity, water conservation practices, etc.

Each of the above consortia provides an opportunity for its members to interact and exchange knowledge at regular meetings and/or working committees. Furthermore, each consortium sends representatives to the meetings of the other group.

The soils work done under IRRI, CIAT,CIMMYT, and IITA all bear on the work under this project. The TVA project to develop new fertilizers for rice is pertinent to soils of high rainfall areas where rice is grown as an upland grain crop.

Following the initiation of this project, a planning conference was held in September, 1969 at Raleigh, North Carolina with representatives of U.S. institutions involved in soil fertility/soil management problems in the humid tropics of Latin America. The following institutions were represented: North Carolina State University, University of Puerto Rico, Tennessee Valley Authority, U.S. Department of Agriculture, University of Florida, Utah State University, International Maize and Wheat Improvement Center (CIMMYT), Agency for International Development, and Cornell University.

At this conference, each institution outlined the soil fertility work which it was conducting and planning to do in Latin America. An outline of the initial experiments proposed by Cornell University for starting the work in Puerto Rico was presented and discussed. There was general agreement that the research proposed was of high priority and would supplement the ongoing work in soil fertility of the other institutions.

A similar conference was held the following year at Raleigh, North Carolina to promote coordination, communication, and liaison among AID-funded projects and grants concerned with tropical soils and fertilizers in developing countries.

A tropical soils research conference was hosted by IITA in Ibadan, Nigeria in May, 1972 in cooperation with the French Agricultural Research Institute (IRAT). Members of the Cornell staff involved in the project participated in the conference which provided a unique opportunity to interact with African soil scientists from several countries in addition to the many French, British, Belgian, and U.S. soil scientists doing tropical soils research. Also there was an opportunity to become familiar with the soils research activities of IITA. Following the conference the Cornell participants visited institutions in several African countries which have ongoing research programs.

Continuing contact has been maintained with IITA, most recently when Dr. Lathwell of the Agronomy Department at Cornell attended the Shifting Cultivation Workshop in Ibadan last July. He had the opportunity to discuss soil fertility research work with IITA soil scientists. He arranged with Dr. Kang of IITA to have soil samples sent to Ithaca from their nitrogen experiments to determine the applicability of simple procedures developed by Dr. Lathwell for determining the nitrogen supplying power of soils of the tropics.

Arrangements have been made with IITA for a cooperative research project entitled "Agricultural Land Use and Potential in Relation to the Genesis and Classification of Soils of a Climatic Sequence on Early Pleistocene and Late Tertiary Sediments in West Africa." Dr. Frank Moorman of IITA, Dr. M. G. Cline, Dr. R. A. Arnold, and Mr. Terry Forbes of Cornell have responsibility for the project. Mr. Forbes will be the main investigator. In addition to IITA, AID, and Cornell, other cooperators will be West African research institutions that cooperate with IITA. This study would appraise the potential performance of different kinds of soils where data are available in the area. It would determine soil properties at benchmark sites from Togo to southeastern Niberia where IITA, IRAT, and Nigerian research stations have data on soil performance. Based on this information the soils would be classifed as bases for extending the information in West Africa and in other tropical regions.

Collaborative arrangements have been established with CIAT and CIMMYT. An informal agreement with CIAT and the Colombian Agricultural Research Agency (ICA) provided the opportunity for two Cornell Ph.D. candidates to do their thesis research on the acid soils of the eastern plains of Colombia on problems of mutual interest related to the objectives of the project. Dr. Eduardo Alvarez, Associate Director of CIAT has recently

visited Cornell and offered his cooperation in our research efforts particularly in connection with the fertility experiments on cassava. A Cornell Ph.D. candidate from Cameroon will soon be going to Colombia to do his thesis research on cassava which includes soil fertility studies.

An arrangement has recently been made between Cornell and CIMMYT for a graduate training and research program to involve a team of five Ph.D. candidates from different disciplines (Soil Science, Plant Protection, Plant Breeding, and Agricultural Economics) to work on a priority problem which would involve a cross-discipline approach. The researchers would be under the guidance of a team of Cornell faculty and CIMMYT. This is a four-year experimental program and will provide continuing contact and association with CIMMYT

5. Proposed Work Plan

a. Scope of Work

The purpose of the research in this project is to develop better soil and water management practices for the humid tropics. Work on both major plant nutrients and micronutrients is included. Aluminum toxicity and means for its control are being studied. Liming and phosphate fertilizers are being tested for their effects on plant rooting and yield.

Grains and edible legumes were used in the early years as test crops but now other important food crops such as cassava and plantain will be used also, especially on those plots which have been maintained for several years and on which it is reasonable to expect measurable residual effects of prior treatment.

It is planned to reduce the effort in Puerto Rico during the next three years, give more attention to the work in Brazil, and develop collaborative programs in other countries. Studies in the new areas will be similar to those in Puerto Rico and Brazil with necessary modifications for on-site testing of the validity of the earlier findings under somewhat different soil and climatic conditions.

Collaboration with the Soils Research Institute at Kumasi, Ghana has been explored with Dr. Obeng, Acting Director, Dr. Ofori, Head of the Soil Fertility Section, and Mr. Halm, Head of the Soil Chemistry Section. They were very much interested in participation in a cooperative research program similar to the project operation in Brazil. The physical facilities at Kumasi are good and there are well-qualified staff members there who would like to participate in a joint effort. The soils of the experimental fields at Kumasi and at a substation are representative of extensive areas in central Ghana. Some are Ultisols, highly acid soils related to those

in Puerto Rico, and others are slightly to moderately acid. There is a substation at Ayinasi, a high rainfall area in the southern part of Ghana which has highly weathered and leached acid soils which are probably Oxisols.

In discussions with staff members at the University of Ghana, they indicated their interest in a collaborative research effort at their research station at Kade which is located in a high rainfall area of evergreen forest and acid soils. The Agricultural Officer of the AID Mission in Ghana, Mr. Ford, was very favorable to the idea of a cooperative soil fertility research project in Ghana between Cornell and either, or both, the University of Ghana and the Soils Research Institute.

Although field research figures prominently in this project, supplementary laboratory and plant research under controlled environmental conditions will continue. The fundamental properties of soils from field test sites and other areas of interest are being studied. This is done both as a guide to design of experiments and to establish the comparability of soils from different locations which have been classified as belonging to the subgroup or family. Greenhouse, lathhouse, and open pot or cylinder trials are being used to give a range of conditions and allow a range of treatments which would be impractical in the field.

The abstract of the Work Plan and Timetable follow. The work is described briefly with target dates for starting and completion. The presentation is organized according to location of the research and then the nature of the particular experiments or sets of experiments. A number of the experiments shown as starting in 1974 and 1975 are extensions of earlier experiments with different crops.

Work Plan; Abstract and Timetable

Location	Starting Date	Expected Completion
1) PUERTO RICO		
a) Nitrogen and phosphorus experiments with cassava on different soils at four locations.	April '73	Dec. '75
b) Nitrogen and phosphorus experiments with plantains on different soils at four locations.	Jan. '74	June '76
c) Nitrogen, phosphorus, potassium, calcium, magnesium, and micro-nutrient experiment with plantains at one location.	April '73	June '76
d) Subsoil liming on high aluminum soil with sorghum as test crop.	April '73	Oct. '74
e) Liming experiments with plantains on five different soils at five locations.	April '73	June '76
f) Soil water extraction patterns of various crops in relation to rooting depth as affected by fertilizer and lime treatments.	Oct. '72	Oct. '74
2) BRASILIA, BRAZIL		
a) Nitrogen experiments: Rates and methods of application of nitrogen for corn, upland rice, sorghum, and root crops on two extensive soils in the Campo Cerrado.	Oct. '72	June '76
b) Phosphorus experiments: Rates and methods of application of phosphorus for corn, upland rice, soybeans or other edible legumes, sorghum, and root crops. Same two soils as above.	Oct. '72	June '76

Work Plan; Abstract and Timetable (cont'd)

Location	Starting Date	Expected Completion
BRAZILIA, BRAZIL (cont'd)		
c) Nitrogen, phosphorus, lime, and micronutrient experiments with grasses and legumes.	Aug. '73	June '76
d) Liming experiments: Deep placement of lime compared with surface applications for corn, sorghum, upland rice, edible legumes and root crops. Same two soils in a) and b).	Oct. '72	June '76
e) Soil moisture studies to determine factors affecting the efficient use of water in the soil under natural rainfall and under irrigation.	Jan. '73	June '77
3) GHANA		
a) Nitrogen experiments: Rates and methods of application of nitrogen fertilizers for cereal grains and root crops on two representative acid soils.	July '74	June '77
b) Phosphorus experiments: Rates and methods of application of phosphorus fertilizer for cereal grains, edible legumes, and root crops at same two sites as above.	July '74	June '77
c) Liming experiments: Effect of deep placement of lime compared with surface applications on cereal grains, edible legumes and root crops. Same two sites as above.	July '74	June '77

Work Plan; Abstract and Timetable (cont'd)

Location	Starting Date	Expected Completion
GHANA (cont'd)		
d) Soil moisture studies: Factors affecting its efficient use; development of improved water management practices in relation to soil fertiltiy requirements. Same two sites as above.	July '74	June '77
e) Micronutrient studies: Identification of micronutrient needs and experiments to determine the most effective rates and methods of application.	July '74	June '77
4) ITHACA		
a) Chemical studies on soil samples from field experiments in Puerto Rico, Brasilia, and Ghana to help interpret field responses to nitrogen, phosphorus and lime treatments and provide a basis for the application of the experimental data to similar soils in other areas in the humid tropics.	April '73	June '76
b) Clay mineralogical properties of the soils from the experimental plots in relation to their effect on ion absorption and release.	April '73	June '76

b. Program of Work -- April 1, 1974 to March 31, 1975

The work this year represents a maturing of several phases of the project in Puerto Rico. The rather intensive work on nitrogen, phosphorus, and liming, using short-term grain crops as test plants, has been followed by the use of longer term crops of major significance to the tropical farmer. Cassava (manioc) and plantain will be used. Their selection was dictated by general practice. Fields are normally planted to one or the other of these crops at the end of a bush fallow cycle before the field is abandoned. As mentioned above the work in Puerto Rico will be reduced substantially during the next three years as the effort in Brasilia is expanded and work is started in other areas.

Additional emphasis will be given to soil moisture relationships and plant nutrition in the coming year. Research results to date strongly point to water availability as a major yield determinant so that it can no longer be ignored because there is "adequate" rainfall.

The work in Brasilia is in the initial stages and will follow from the work already done in Puerto Rico. As in Puerto Rico, corn was the first crop but other short-term crops will follow before planting medium or long-term crops. An intensive study of moisture relationships will be part of the research at Brasilia from the outset.

It is planned to initiate a program in Ghana with experiments similar to those being conducted at Brasilia.

A detailed description of the research activities which are planned is given below.

1) Puerto Rico

a) Nitrogen Experiments with Cassava and Plantains

Following the four crops of corn and one crop of upland rice, cassava was planted in April, 1973, at the four experimental locations in Puerto Rico having representative soils with characteristics similar to the acid soils so extensive in the humid tropics (Oxisols and Ultisols). As with the cereal crops, the objective is to determine the efficiency of utilization of different rates of applied nitrogen in relation to the productivity of cassava on the different soils. In addition to the yield data, soil and plant analyses will help determine movement of nitrogen through the soil, uptake by the crop, and losses through leaching and volatilization.

Up until now the main emphasis in the nitrogen experiments has been given to the cereal food crops. In accordance with the original plan, attention is now directed to responses of important tropical root crops, such as cassava, to levels and methods of nitrogen applications. A new high protein cassava variety is being used.

Following the harvest of cassava, the next crop at the four locations will be plantains. In addition to these experiments an extensive field trial with plantains is being carried out on another clayey Ultisol in cooperation with the U.S.D.A. Agricultural Research Service soil scientists to determine nitrogen responses in various combinations with phosphorus, potassium, lime, and micronutrients.

b) Phosphorus Experiments with Cassava and Plantains

Following the completion of field trials of the cereal crops on a representative clayey Ultisol in Puerto Rico on rates and methods of application of phosphate fertilizer, cassava will be the test crop to be followed by plantains. In addition to yield responses to different levels and methods of application, the residual effects of applied phosphate to successive crops will be measured.

On a clayey Ultisol, at another location in Puerto Rico, yield responses to levels and methods of phosphate application to the plantains will be determined.

Chemical studies on phosphate retention and availability will be made on soil samples from the different field plots. The objective will be to develop extraction procedures for soil tests which would provide better correlations with crop response than can now be obtained on many Oxisols and Ultisols.

c) Soil Acidity and Liming Experiments

On five different Oxisols and Ultisols in Puerto Rico the field trials will be continued in order to get yield response to different levels of lime on a succession of crops. Following two crops of corn, one of green beans, one of sweet potatoes, one of rice, and one of Irish potatoes, plantains will be grown during 1974-1975. The objective of these experiments is to determine the minimum levels of lime required for optimum yields of various crops on the different soils and to devise better laboratory methods for determining lime requirements.

On a representative clayey Ultisol high in exchangeable aluminum the effect of incorporating lime in both the subsoil and surface soil will be compared with liming only the surface soil. The test crop will be sorghum which is particularly sensitive to aluminum toxicity. This work will be done in cooperation with the U.S.D.A. Agricultural Research Service Soil scientists.

The field trials will be supplemented with laboratory and greenhouse studies with special attention being given to factors which affect aluminum toxicity to crops. Previous studies have shown the effect of the kind and concentration of other ions in solution on aluminum toxicity and these studies will be continued. The effect of organic matter in reducing aluminum toxicity, shown in preliminary greenhouse trials with sorghum, will be studied with other crops.

d) Soil Moisture Studies

One of the most critical factors affecting crop response in the soil fertility experiments is availability of soil moisture. A deficiency of soil moisture frequently occurs during the rainy season when there are periods with little or no rainfall. Preliminary studies in Puerto Rico on infiltration, movement within the profile, storage, and availability of soil moisture have pointed up the necessity for a more critical investigation of the soil moisture factor in relation to crop response to applied fertilizers and lime. Root development in the subsoil is restricted in many of the acid Ultisols and Oxisols by the relatively high amount of aluminum and/or manganese and deficiency of calcium and/or other nutrients. Consequently, even though there may be adequate subsoil moisture storage during the dry periods in the rainy season, root development is restricted and the stored water cannot be exploited. It is planned to measure the soil water extraction patterns of various crops in relation to rooting depth as affected by the application of fertilizers and lime. This work is being done on representative Ultisols and Oxisols in Puerto Rico.

2) Brazil

a) Soil Fertility and Soil Moisture Studies on the Campo Cerrado

In collaboration with the Ministry of Agriculture and North Carolina State University a series of field experiments was initiated in October, 1972 on a soil at the experiment station near Brasilia which is representative of millions of hectares of the deep, well-drained highly acid soils of the Campo Cerrado. The experiments now underway will measure responses of corn to different levels and methods of application of nitrogen, phosphorus, and lime. These experiments are similar in design to those which have been conducted in Puerto Rico. Though the soils are similar in many characteristics to those under investigation in Puerto Rico, there are important differences and the climatic environment is different.

Following the first crops of corn it is planned to have a sequence of crops such as upland rice, soybeans or other edible legumes, sorghum,

and root crops. Irrigation facilities are available so that it is planned to have continuous cropping throughout this year. Soil moisture arrangements will be made to determine water stress in relation to root penetration during the cropping periods. Particular attention will be given to subsoil root penetration and soil moisture extraction in a liming experiment involving deep placement of lime in comparison with surface applications. The relatively high percentage of soluble aluminum and very low calcium and magnesium are important factors in these soils limiting the productivity of many crops. Potassium is also very low in these soils and its availability in relation to calcium and magnesium will be investigated.

b) Fertility Trials on Pasture and Hay

As considerable emphasis will be given by the Ministry of Agriculture to beef cattle production on the Campo Cerrado, it is planned to initiate soil fertility trials with grasses and legumes in collaboration with the University of Florida forage and livestock specialists who have been contracted to develop a livestock improvement program for the Campo Cerrado with headquarters in Brasilia.

3) Ghana

a) Soil Fertility and Moisture Studies

It is planned to initiate field, greenhouse, and laboratory soil fertility research in collaboration with the Soils Research Institute at Kumasi and the University of Ghana near Accra. The priority areas for the suggested research on representative acid soils of the area may include: (1) methods of supplying the nitrogen requirements of important food crops; (2) methods of economically supplying phosphorus for sustained crop production; (3) methods of economically correcting soil acidity as a factor limiting crop production; (4) soil moisture studies to determine water utilization patterns and to develop methods for more efficient use of water in relation to nutrient uptake; and (5) determination of micro nutrient deficiencies through observation, soil analysis, plant analysis, and yield response experiments.

4) Ithaca

a) Clay Mineralogy Studies

In order to better interpret the reactions of applied nutrients in the soil fertility experiments, mineralogical analyses will be continued. Special attention will be given to the interaction of the non-crystalline iron and aluminum oxides and organic matter and its influence on the charge characteristics of the surface horizons. The soil mineralogical properties which influence the absorption and release of added phosphorus to the crops will be determined. Also the affinity of the exchange complexes for potassium relative to that of calcium and aluminum will be measured on those soils which have a relatively low level of potassium.

c. Project Staffing

The staff assignments for the coming year at Cornell and at the niversity of Puerto Rico are shown on the next chart. The greatest mount of professional time will be contributed by the staff in Puerto ico, Brazil, and Ghana.

ne staff posted in Ithaca will be expected to spend a considerable amount f time in Puerto Rico, Brazil, and Ghana or traveling in other tropical ountries.

Personnel - April 1, 1974 to March 31, 1975

Location	Man Months
PUERTO RICO	
Professional	
R. H. Fox - Soil Scientist	12
E. J. Brenes - Soil Chemist	6
R. De Valle - Agronomist	6
Y. Fraticelli	6
H. Talleyrand - Res. Assistant	12
Nonprofessional	
V. Santiago - Technician	
M. Malave de Garcia - Secretary	12
Laborers (Field)	12
Laborers (Laboratory)	50
	20
BRASILIA, BRAZIL	
Professional	
G. C. Naderman - Soil Scientist	12
D. Bandy - Res. Assistant	12
J. Pruntel - Res. Assistant	3
Nonprofessional	
E. Martins - Field Assistant	12
---------- - Lab. Assistant	12
GHANA	
Professional	
---------- Soil Scientist	2
---------- Res. Assistant	9
Nonprofessional	
---------- Field and Laboratory Assistant	9

Personnel (cont'd)

Location	Man Months
ITHACA	
Professional	
M. Drosdoff - Soil Scientist	3
R. M. Weaver - Soil Scientist	6
*D. J. Lathwell - Soil Scientist	2.5
*T. W. Scott - Soil Scientist	2.5
*D. R. Bouldin - Soil Scientist	1
*R. Musgrave - Crop Scientist	1
---------- Res. Assistant	12
Nonprofessional	
M. Boyukcolak - Secretary	

*Associated with project but not to be paid from project fund

d. Projected Budget

Category	Allocation by Fiscal Year (thousands of dollars) '74	'75	'76
Salaries	160	162	162
Overhead	55	56	56
Travel and Transportation	18	16	16
Allowances	15	16	16
Other Direct Costs	5	5	5
Equipment, Vehicles, and Supplies	22	20	20
TOTAL	275	275	275

NOTE: The costs at the University of Puerto Rico are included in the line items of this budget. As the work in Puerto Rico is phased down, the reduced costs will be offset by the work in Brasilia and that proposed for Ghana.

An increasing budget to affect normal increments to an increasingly competent staff and to offset inflation will be needed to maintain the current level of effort.

6. Research Contractor's Competence

The Department of Agronomy of Cornell University is recognized as one of the leading soils research and teaching groups in the United States. In addition, Cornell has had a long association with tropical agriculture in many parts of the world especially in the Philippines and in Latin America. The department attracts a large number of foreign students seeking both the disciplined training and prestige associated with a Cornell degree. Of the more than 60 graduate students in the department, over half are from foreign countries and most of these are from tropical countries. The department has recently been authorized to have a senior faculty position on state supported funds with a full-time commitment to world soils. The College of Agriculture, therefore, will now have nine faculty in seven departments supported by state funds with a full-time commitment to international agriculture. In addition, the director of the office of International Agriculture is supported by state funds.

Of the sixteen faculty in the Department of Agronomy who are involved in research, training, and teaching in the various soil science disciplines, ten have had from six months to four years or more of experience in tropical and subtropical environments or are now on such assignments. The Cornell staff assigned to the project, as a result of service in the tropics, is familiar with the problems in those regions and is well qualified to conduct the necessary research activities. The project director, Dr. Drosdoff, has spent most of his professional career working in the tropics and subtropics on problems of these regions.

Soil science at Cornell has available approximately 50,000 square feet (net) of laboratory, office, and service space in a large modern facility. This is fully equipped with the most modern furnishings and equipment.

Library resources at Cornell include a) Mann Agricultural Library, considered outstanding among University libraries in the United States and b) Olin Research Library, a relatively recently constructed facility equipped for graduate student and staff research and study. It ranks among the first ten University libraries in the country.

The University of Puerto Rico, the subcontractor on this project, has established itself as one of the leading Universities and research institutions located in the tropics. The staff is also technically well qualified and is working full time in tropical soils and agronomy. The University of Puerto Rico has an excellent library with emphasis on materials relating to tropical agriculture.

7. Research Linkages

a. The research carried on in Puerto Rico is cooperative under a subcontract with the University of Puerto Rico and several staff members of the Agricultural Experiment Station have been assigned to the project. There is also excellent collaboration with U.S.D.A. soil scientists stationed in Puerto Rico.

b. Close collaboration is maintained with North Carolina State University which has a related research project, "Agronomic-Economic Research on Tropical Soils."

c. The research activities initiated in Brasilia have been developed cooperatively with the Ministry of Agriculture scientists and in collaboration with North Carolina State University.

d. Cornell is one of five Universities including North Carolina State, Hawaii, Puerto Rico, and Prairie View, Texas, in a University Consortium on Soils of the Tropics. Semi-annual meetings of representatives of Consortium members and workshops provide opportunities for exchange of information and ideas on tropical soils research activities.

e. A tropical soils research conference held in Ibadan, Nigeria in May, 1972 was sponsored by the International Institute of Tropical Agriculture (IITA) in cooperation with the French Agricultural Research Institute (IRAT). Members of the Cornell staff involved in the project participated in the conference which provided a unique opportunity to interact with African soil scientists from several countries in addition to the French, British, Belgian, and U.S. soil scientists doing tropical soils research. Also, there was an opportunity to become familiar with the soils research activities of IITA. Following the conference the Cornell participants visited institutions in several African countries which have ongoing soils research programs.

f. As Chairman of the Tropical Soils Committee of the National Research Council for two years, the project director was in frequent communication with the other eleven soil scientists on the Committee who all had much experience doing soils research in the tropics and who represented a broad spectrum of soil science disciplines. The committee was composed of six soil scientists from the United States and six from France, Belgium, England, and Holland with long experience in the tropics of Africa, Asia, and Latin America. The Committee met formally three times for a week each time to discuss all aspects of soil research needs of the humid tropics. The reports which were prepared formed the basis of a book on Soils of the Humid Tropics, published in June, 1972.

g. An informal collaborative arrangement was established with the Colombian Agricultural Research Agency (ICA) and the Institute of Tropical Agriculture in Colombia (CIAT) for two graduate students to do their thesis research on the acid soils of the eastern plains of Colombia (Llanos). A graduate student from Colombia is now at Cornell and will be doing his thesis research on a soil fertility problem on the soils of the Llanos.

h. Dr. Silva of the University of Hawaii spent his sabbatical year at Cornell working on crop response to applied silicate, comparing soils from Hawaii with related soils from Puerto Rico. A graduate student from the Dominican Republic became interested in this subject and has done his thesis research on crop response to applied silicate on soils from the Dominican Republic which are low in soluble silica. Another graduate student from the Dominican Republic has done his thesis research related directly to the project.

i. Dr. Coulter, tropical soils advisor of the Overseas Development Administration of England, was a visiting scientist on the campus for six months. His many years of experience in Malaysia and the Caribbean Islands and knowledge of tropical soils problems in Africa, Latin America, and Asia made him a valuable consultant for many of the students who were developing their ideas for research in their home countries.

j. New fertilizers prepared by TVA have been used in the field trials of the project. Cooperation with the International Fertilizer Development Staff at TVA is on a continuing basis.

k. Regular communications have been carried on with FAO soil scientists in Rome and other stations and there has been a periodic exchange of publications.

8. Dissemination and Utilization of Research Results

a. As segments of the research project are completed, the data are assembled, analyzed, and interpreted and reports are prepared for conferences and seminars and for publication in appropriate technical journals. Following is a list of publications, articles submitted for publication, theses, and reports prepared for conferences:

1) Sources of Nitrogen in Tropical Environments. Donald C. Kass Matthew Drosdoff. Agronomy Mimeo 70-9. 1970.

2) Relationships Among Physical and Chemical Properties of Representative Soils of the Tropics from Puerto Rico. Warren R. Philipson and Matthew Drosdoff. Soil Sci. Soc. Amer. Proc. 36:815-819. 1972.

3) Nitrogen Fixation by Azotobacter paspali in Association with Bahiagrass (Paspalum notatum). Donald C. Kass, Matthew Drosdoff, an Martin Alexander. Soil Sci. Soc. Amer. Proc. 35:286-289. 1971.

4) Nitrogen Fertilization in the Humid Tropics. Richard H. Fox. Paper presented at the Tropical Soils Research Conference in Ibadan, Nigeria May 22-29, 1972 and published as an Agronomy Department Mimeo 72-17.

5) Nitrogen Supplying Power of Some Tropical Soils of Puerto Rico and Methods for Its Evaluation. D. J. Lathwell, H. B. Dubey, and R. H. Fox. Agronomy Journal. 64:763-766. 1972.

6) Root Responses of Three Gramineae Species to Soil Acidity in an Oxisol and an Ultisol. E. Brenes and R. W. Pearson. Presented at the Annual Meetings of the Southern Agricultural Workers Association in Jacksonville, Florida on February 3-7, 1971. Soil Science (in press).

7) Measurement of Aluminum Toxicity: I. Effects of Aluminum in Soil Solution on Root Growth. H. G. Zandstra and D. R. Bouldin. Submitted for publication to the Soil Science Society of America Proceedings.

8) The Role of Organic Matter in the Inhibition of Aluminum Toxicity in an Ultisol. Publio Santiago. M.S. Thesis. Cornell University. 1972.

9) The Fats of Nitrogen Fertilers Applied to Tropical Soils. F. F. Ferreira. M.S. Thesis. Cornell University. 1971.

10) Aluminum Toxicity in Some Highly Weathered Soils of the Tropics. Hubert G. Zandstra. Ph.D. Thesis. Cornell University. 1971.

11) Mineralogy of Highly Weathered and Leached Soils of the Humid Tropics. R. M. Weaver. McGraw-Hill Yearbook of Science and Technology. 1973.

12) Clay Mineralogy of Ultisols and Oxisols of Puerto Rico. R. M. Weaver. To be submitted to Soil Science.

13) pH Dependent Cation Exchange Selectivity of Oxisols and Ultisols. R. M. Weaver. To be submitted to the Soil Science Society of America Proceedings.

14) Influences of Amorphous Iron Oxides and Organic Matter on the Charge Characteristics of Highly Weathered Soils of the Tropics. R. M. Weaver. To be submitted to Clays and Clay Minerals.

15) Chemical and Clay Mineral Properties of a Highly Weathered Soil from the Colombian Llanos Orientales. R. M. Weaver. Agronomy Mimeo 72-19. 1972.

16) Cultural Systems on Tropical Soils. M.Drosdoff. Proceedings of the Tropical Soils Workshop, Prairie View A&M College, Texas. 1972.

17) Organic Phosphorus in Soils with Special Interest in Soils of the Tropics. K. J. Roberts and R. M. Weaver. Agronomy Mimeo 73-1. 1973.

18) Limitations to Productivity of Some Oxisol and Ultisol Surface and Subsoils. K. Dale Ritchey. Ph.D. Thesis. Cornell University. 1973.

19) Use of Wick-Watering for Greenhouse Pots in the Tropics. K.Dale Ritchey and R. H. Fox. 1973. Submitted for publication to Tropical Agriculture (Trinidad).

20) Limitations to Productivity of Some Oxisol and Ultisol Subsoils. K. Dale Ritchey and R. H. Fox . 1973. Submitted for publication to Journal of Agriculture of the University of Puerto Rico.

21) Denitrification Losses from Humid Tropical Soils of Puerto Rico. H.D. Dubey and R. H. Fox. 1973. Submitted for publication to Soil Science Society of America Proceedings.

22) Resultados Preliminares de Estudos com Calcario e Fosforo num Latosol Vermelho Escuro Textura Argilosa, Fase Cerrado. W. Soares, E. Zoborowsky, G. Naderman, E. Gonzales, and R. Yost. Presented at the XIV Brazilian Congress of Soil Science in Santa Maria, RGS. July 1973.

23) Soils of the Central Plateau of Brazil. M. G. Cline, Cornell University and S. W. Buol, North Carolina State University. Agronomy Mimeo 73-13. 1973.

b. Meetings of the University Consortium on Soils of the Tropics sponsored under an AID 211(d) grant, have provided an important way to disseminate the findings of this project. Each of the member universities is building both its research and teaching competence in tropical soils. The research of this project will be immediately available for related research and passed on to students from many countries.

c. The Project Director served as Chairman of the Committee on Tropical Soils of the National Academy of Sciences. The outgrowth of the work of the committee resulted in the publication of a book in June, 1972 on Soils of the Humid Tropics. This book contains a section on Research Needs and summary articles on present knowledge of tropical soils in many subject matter areas. This book has a wide distribution among research workers, students, and teachers interested in soils of the tropics.

d. A number of graduate students, international and U.S., have either been directly involved in the project or in research related to the project. Mr. Ferreira and Mr. Tio of the Dominican Republic did their M.S. thesis research on a topic directly related to the project as did Mr. Santiago from Venezuela. Both of these men have returned to positions in their home country. Mr. Tio has been appointed head of the Soils Department in a University in the Dominican Republic. Dr.Zandstra of Canada did his Ph.D. thesis research on a topic directly related to the project and is now assigned to Colombia on a technical assistance project sponsored by the Canadian Government. Dr. Naderman of the U.S. did his thesis research in Colombia on a topic related to the project and is now in assignment in Brazil working on the project in cooperation with the Ministry of Agriculture. Mr. Ritchey of the U.S. has completed his Ph.D. thesis research in Puerto Rico directly related to the project and has a career commitment to continue to work in the tropics. He now has a position with the University of Wisconsin and is stationed in northeast Brazil. Several other graduate students from the U.S. and abroad are initiating their thesis research on subjects related to the project objectives.

e. Between 500 and 1,000 farmers and extension agents visited the intensively managed plantain fertility experiment in Puerto Rico. The yield of approximately 68,000 plantains per acre in this experiment was 20,000 more than the previous record for Puerto Rico and 45,000 more than that attained by the average farmer.

f. Though the work in Brazil has been underway for only about a year, the results of the initial experiments are getting wide dissemination. In addition to the preliminary paper presented at the Brazilian Congress of Soil Science in Santa Maria in July 1973, several popular articles have been printed in the "Supplemento Agropecuario" of the Diario de Brasilia in February and March of 1973. An agronomy class of the University of Brasilia visited the experiments in March 1973, and a summary of the results to date was presented at the University of Brasilia in July, 1973.

g. The report by Cline and Buol on the Soils of the Central Plateau of Brazil was submitted to Dr. Roberto Meirelles, co-director of the Brazilian Agricultural Research Corporation (EMBRAPA). He asked for 100 copies for distribution to all those involved in research on the Campo Cerrado.

9. Budget Analysis

The budget presented for the contract year beginning April 1, 1974 is reasonable in the light of the plan of work. Salaries make up the greatest portion of the project cost. Overhead which is set by university regulation is within an acceptable range, twenty percent on an overall project cost basis.

10. Internal and External Review

This project has been reviewed frequently by TA/AGR officers over the past several years. During 1972 both Dr. Kelley, Director, and Dr. Gill, Soils Management Specialist, reviewed the work of this project at Cornell and in Puerto Rico. A utilization review was held on March 20, 1973. A supplementary review was conducted on September 10, 1973 after the Project Director, Dr. Drosdoff, returned from an on-site inspection of the work at Brasilia with Dr. McCants, Director of the North Carolina State University Project.

A formal progress report was prepared for the RAC and presented at its 32nd meeting on January 28, 1971.

Progress on the project has been more than satisfactory. The contractor has followed the directions from AID/W in extending the research in Puerto Rico to Brazil and arranging work in Africa. The general validity of the findings can only be verified through broad testing.

This Project Statement was reviewed and approved by the Inter-Bureau Technical Committee prior to review by RIGC.

11. Proposing Office General Evaluation and Recommendation

The project continues to rate high among the projects overseen by the Office of Agriculture and is an integral part of our soil and water program. The project is directed at the most urgent problems we face, buying time with increased food production until population growth rates can be brought into balance, and improving the lot of the average farmer. The target area, the humid tropics, is one of the most critical areas in the race between mouths and food supply. It is also one of the areas with the greatest potential for increasing food production. By providing new or better ways to grow more food, the project will also provide the basis for new jobs on the farm, in trade and in transportation. Since it will allow more intensive use of available land resources, it serves the needs of the farmer of limited means and small acreage.

This project holds a key spot in the network of soils research sponsored by AID. It is directly linked to the North Carolina project through the work in Brasilia and in constant touch with the other AID sponsored soils research through the 211(d) consortium.

A three-year extension of the contract will allow for planned continuation of the research activities in Puerto Rico, the extension of the cooperative research recently initiated in Brazil, and the possibility of similar studies in other locations in Latin America or in Africa.

Cornell University has performed satisfactorily under this contract and TA/AGR recommends a three-year extension of this project.

Omer J. Kelley, Director
Office of Agriculture

John L. Malcolm, Project Manager

John B. Cordaro
Chief, Program Division

PROJECT STATEMENT SUPPLEMENT

Soil Fertility in the Humid Tropics
Cornell University, AID/csd-2490

The critical need for developing the acid soils of the humid tropics and the necessity for research to support this development was acknowledged during the RIGC Review. There was also general agreement that the results of the experiments reported to date and the line of researc described in the work plan were directed toward the key factors in food production on these soils. The advisability of continuing the research in Brazil was questioned. TA/AGR believes that the work in Brazil is justified because it carries out commitments already made, contributes to a combined attack on an urgent problem and many of the results will be applicable elsewhere. Selection of potential sites for research in Asia will be started this year and active field work will begin when starting such work will not damage the work in progress.

The major RIGC challenge to Cornell's plan for the extension period was on the advisability of continuing work in Brazil when the Agency had to phase out technical assistance on a grant basis to that country. The suggestion was made that the research be moved to Asia, perhaps Indones or the Philippines.

In support of going on with the work at Brasilia, a commitment was made to work in Latin America and on soils of the type found in the Campo Cerrado when the project was first approved by the Agency. Brazil offe a special opportunity in terms of underutilized soils resources, availability of capable local scientists and a commitment on the part of the Government to translate research results into farm practice. While the is a degree of site specificity in all soil research, much of the information which can be expected from the research in Brazil will be transferable. From an operational standpoint, one major shift was init during the past summer opening the way for new work in Ghana and phasi down the work in Puerto Rico. Starting on work in a second new locatio without a substantial input of additional money and manpower, would dil the effort to an ineffectual level.

Terminating the work in Brazil now is inadvisable. Losing the momentum generated at Brasilia and abandoning experiments in progress would ent major technical sacrifices without commensurate gains. Such an abrupt change, renigging on agreements reached in good faith, has political and simple creditability consequences which should not be ignored by AID.

Phasing out the technical assistance grants to Brazil should not be allowed to interfere with the research to be conducted under this proj

The expenditure in Brazil is modest, on the order of $75,000 per year. Most of this goes for salaries and maintenance of the U.S. scientist assigned to the post and to cover temporary duty of Ithaca based senior staff. The Government of Brazil is contributing several times as much in staff, facilities, and related services. For example, during a recent field tour of Drs. Cline and Buol, four senior specialists in soil genesis and classification were assigned to travel with them and make full use of their talents.

The new experiment station at Brasilia is largely dedicated to work directly related to the project. The director, a trained soil scientist, is participating in the research himself. An "Ingeniero Agronomo" and an experienced technician are assigned to the project on a full time basis. All the necessary field labor is supplied to the project. The laboratory was fully equipped and necessary field machinery purchased as the Brazilian response to and support of the project.

The cooperation does not end with the official government support. The University of Brasilia has made its computer available to the project staff. Also, project personnel have been welcomed at the radio isotop laboratory and allowed to use such specialized equipment as the scintillation counter for radio tracer analysis. The International Atomic Energy Commission Laboratory in Sao Paulo has given assistance and will be providing isotopes for plant nutrient recovery experiments.

North Carolina State University has two research assistants assigned to Brasilia whose work is intimately linked to the Cornell project. These two young men look to the senior Cornell scientist for their day to day technical support.

USAID/Brasilia has been extremely helpful to the project, providing transport, household furnishings, and supporting services. Very concrete evidence of Mission support.

Such cooperation and facilities are not to be found everywhere, nor does access come quickly. The original concept of the project, five years ago, was that the sparsely settled lands of the Campo Cerrado in Brazil and the Llanos Orientales of Colombia were contributing very little to those nations. The potential of these extensive areas represented a major challenge but the practicality of their utilization remained to be demonstrated. The soil research on this project was not directed toward marginal improvements of extensive grazing practiced by the large land holders but toward intensive management and high production of basic foods. Providing the technology to make this land highly productive would also make small-holder and tennant farming economically feasible. The poor yields, normal in the Cerrado, have condemned small-holders to poverty at the very best and most often assure that land was retained in large blocks, keeping the campesino a landless laborer or itinerant cowboy.

Transferability of the results obtained in Brazil to Asia was discussed at length. The evidence is that there should be a high transfer probability. According to the PSAC report, there are over 1.2 billion acres of "tropical" soils in Southeast Asia, of which 900 million are well drained acid soils, now classed as Oxisols and Ultisols. These are the soils being studied under the project in Puerto Rico and Brazil. These soils are high in iron and aluminum oxides, leached of bases with kaolinite as the predominant clay mineral. Aluminum and manganese toxicity, phosphate fixation and restricted plant root development in these soils are major problems. The work in Puerto Rico and Brazil will provide the basic guidelines and tested measurement techniques permitting the scientific management of similar soils in Asia, Africa, and elsewhere. Local adaptation of practices will always be necessary whether the results of the research are transferred from Brasilia to Java or from Java to Suluwesi.

As work is concluded in Puerto Rico, extension of the project to a field location in Asia, such as Indonesia or the Philippines would be reasonable and is acceptable to Dr. Drosdoff, the project director. Spreading the work to another location now or in the near future would require abandoning experiments already under way. It would also mean breaking faith with cooperators who have committed their own resources. There will be an opportunity to explore research opportunities in Asia over the next year and to lay the ground work for expansion of the project several years hence, the phasing which accords with Cornell's proposal.

TA/AGR:JLM:10/15/73

Project Review Report - RIGC (10/4/73)

Project: Soil Fertility in the Himid Tropics - Cornell University

Project Manager: John L. Malcolm

Discussion Highlights

1. Parameters of Project - Mr. Dalton questioned the limits of the investigation. Would it have to go on endlessly and in every country where there was a problem in understanding management of tropical soils? TA/AGR stated there was much to be learned about tropical soils and that knowledge obtained under this project in Brazil, Puerto Rico, and in West Africa would be extended and applied to problems in Asia and elsewhere in Africa and Latin America. Further they did not see any end to the search for more information on tropical soils but this did not mean that A.I.D. would be continuously financing this research.

2. Location of Project - RIGC members expressed a deep concern as to the rationale behind using Brazil as the major site of the research. In part, the concern centered upon A.I.D.'s plan to terminate assistance to Brazil and in part on the neglect of Asia, where a large population could benefit from improved knowledge in regard to tropical soils. TA/AG, responded that it will be possible to extrapolate knowledge gained from Brazil to Asia. Further they stated that the arrangements now worked out with Brazilian organizations, the government and soil scientists there, made Brazil a highly desirable place to do the research. To give up Brazil as a site and start up elsewhere would add to the cost and time needed for the research.

3. Rationale for Location of Project - TA/AGR was requested to re-do the project statement to reflect the elements that have gone into the decision to continue the research in Brazil as opposed to shifting the project to Asia. This should be a statement that would justify the action in face of the strong arguments presented for not continuing research in a country where A.I.D. is terminating its assistance.

Action: RIGC recommended that the project be sent to RAC for review provided the justifying statement as to site be sent forward as part of a revised project statement.

Moved by Cooper; seconded by Rixse

Vote: Unanimous

SUMMARY OF RAC RECOMMENDATIONS TO A.I.D.
PROPOSALS REVIEWED AT THE DECEMBER 3-4, 1973 MEETING

505
KPA4

1. Soil Fertility in the Humid Tropics (extension) - Cornell University. Duration of extension, three years (June 30, 1974 to July 31, 1977); additional cost, $825,000. Whitney, Adams, D. Peterson, Ruttan. 1/

Recommendation: That: (1) the extension of the project for the three-year period at the level of funding be approved as requested; (2) the expansion of the research to a third area in Africa be implemented if possible as the Puerto Rico activity is phased down and resources become available.